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(54) TEMPERATURE ACTUATED CONNECTORS AND ACTUATORS

(71) We, RAYCHEM CORPORATION, a Corporation organised according to the laws of the State of California, United States of America, of 300 Constitution Drive, Menlo Park, California 94025, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to connectors and actuators, more especially to electrical connectors which utilise the force generated by a resilient member to establish a secure and clean electrical connection.

The present invention is especially applicable to the formation of an electrical and mechanical connection between a conductor and a printed circuit board. In the past, such connections have been commonly made by a plug-in type connection where the conductive board fits into a slot and a conductive resilient member contacts a conductive portion of the board. Such connections have several disadvantages. First, the board is not tightly held in its plugged-in position. Secondly, the electrical connection tends to degrade if the contact is not exercised.

A soldered connection can be used to connect a conductor to a printed circuit board. Such a connection does not have the "plug-in" capability and requires resoldering at any time the printed circuit board needs to be removed or replaced. When multiple connections are involved, this disadvantage is particularly acute.

An improved connector is disclosed in British Patent 1,395,601. This connector utilizes a heat recoverable metallic member disposed about a resilient member, such as a forked member with resilient tines. A conductor is inserted between the tines and the heat recoverable metallic member is caused to shrink, thereby forcing the tines inwardly and against the conductor. Such a device is somewhat limited in amount of movement, and is also relatively expensive to manufacture and thus the need for an improved connector exists.

The present invention provides a temperature-actuatable snap-action device which assumes one configuration above a transition temperature or temperature range and another configuration below said transition temperature or temperature range, which device comprises two interacting spring members at least one of which exhibits a substantial change in force/deflection characteristics on passing through the transition temperature or temperature range and at least one of which has a non-linear force/deflection curve having a maximum therein through which it passes as the device snaps from one configuration to the other.

Preferably only one of the spring members exhibits a substantial variation in force/deflection characteristics on passing through the transition temperature or temperature range; the other spring member preferably exhibiting a subtantially negligible change in force/deflection characteristics with temperature, and, for convenience, the devices of the present invention will be described in terms of this preferred embodiment.

Also, in practice, the transition temperture will frequently be a narrow temperature range and, for convenience, references hereinafter to a transition temperature are meant to include this possibility.

The devices of the present invention exhibit a snap-action in the movement between their two configurations. This

"snap" action is a very important feature of the devices of the present invention which may be utilised in, for example, the opening and closing of valves, as well as in connectors of the type described previously. One of the spring members, advantageously the member which exhibits the variation in force/deflection characteristics with temperature, has a non-linear force/deflection curve having a maximum so that, under the influence of the other spring member and in absence of external restraint, said spring member passes through this maximum as the device is heated or cooled through the transition temperature. (It will be appreciated that this spring member exhibiting varying force/deflection characteristics with temperature will have different force/deflection curves above and below the transition temperature, and, therefore, that in this case the snap-action will typically arise from a movement from one side of the maximum on one temperature cruve to the other side of the maximum on the other temperature curve.)

Amongst suitable spring members having maxima in their force/deflection curves there may especially be mentioned longitudinally loaded leaf springs. However, other types of spring members, for example Belleville springs, can also advantageously be used.

The spring member which exhibits a variation in force/deflection characteristics on passing through a transition temperature, may be made from a polymer or non metallic elastomer of the type known to exhibit a relatively large modulus change at a certain temperature.

However, preferably, this member is made from a metal, especially a sometimes so-called "memory" metal. Suitable metals are disclosed, for example, in U.S. Patent No. 3,012,882, U.S. Patent No. 3,174,851, Belgian Patent No. 703,649, Belgian Patent No. 755,271 and Belgian Patent No. 769,468. Especially suitable metals are alloys containing about equal atomic proportions of titanium and nickel. They typically have an austenitic secant modulus of about 12,000,000 PSI. at a strain of 1/2% and a martensitic secant modulus of about 850,000 PSI at a strain of 5%. (A secant modulus (of elasticity) is the slope of a line drawn from the origin of the stress-strain curve of a material to any point along the curve.) This large difference in secant modulus coupled with the large variation in strain makes these alloys particularly suitable for use in the thermally actuatable devices of the present invention. Relatively large amounts of force and movement per unit volume of material are attainable by their use. It should also be noted that the stress and strain applied must be such that the material does not deform permanently to any substantial degree during repeated cycling. An initial permanent or plastic deformation is allowable but it must not continue on cycling because if it does, the configurations between which the members move will vary with each cycle and that is undesirable.

Other alloys are known which exhibit similar phenomena and examples of such alloys are disclosed in A. Nagasawa, 31 J. Phys. Soc. Japan No. 1, July, 1971 pp. 136—147. Amongst such alloys there may be mentioned cadmium-gold, copper-aluminium-nickel, indium-thallium, uranium, molybdenum and uranium-niobium, some of which are referred to in the above-mentioned patents.

In general the significant change in modulus occurs at the transition temperature between the martensitic state and the austenitic state, the exact temperature varying according to the exact composition of the alloy. (In practice, as mentioned previously, the transition from the martensitic state to the austenitic state generally takes place over a narrow temperature range.) Furthermore, as hysteresis sometimes occurs, the transition temperature may vary depending on whether the metal is being heated or cooled.

The devices of the present invention are especially suitable for use in establishing strong electrical connections; one of the most important applications being in the establishment of such connections with printed circuit boards. For this reason, *inter alia*, it is especially preferred that the transition temperature of the metal employed to give temperature-variable force/deflection characteristics to the device should be lower than ambient temperature. This has several advantages. First of all it is then not necessary for the devices of the present invention to be provided with a heating element in order to cause transition and, consequently, the snap movement desired) this simplifies the devices and is economically desirable. All that is required is a separate cooling tool which can be used to bring a large range of devices into the low temperature state prior to use. In some cases it may be advantageous to use a heating tool to help complete the transformation, but even in these cases a separate heating tool can be used over a wide range of articles.

Secondly, the choice of a material with a low transition temperature avoids the necessity to use high temperatures. Apart from the obvious advantages of avoiding high temperatures it should be pointed out that in the devices of the present invention where the high modulus of one spring member is utilised at ambient temperture the tendency of metals to relax at high

temperatures is substantially avoided. Thus the devices are able to maintain high interfacial pressures on the contacts being made despite the fact that the making of the contact automatically introduces a high strain into the metal. Quite surprisingly, the devices of the present invention can readily be used and re-used many times by cycling the temperature, because the memory metal of the spring member is not permanently strained or "set" when the contact is made. For this reason also the devices of the present invention can be re-used in a situation different from that in which they were first used. That is to say, having been used to form a contact with, for example, a thick printed circuit board, they can readily be re-used with a thinner printed circuit board. These surprising and desirable characteristics might not be exhibited if the transition temperature was high.

A third advantage of using materials which exhibit a high modulus at ambient temperature is that this can be used to generate the contact force. That is to say, the material is not used simply to actuate a second member which generates the force. For this reason the contact forces obtained in the devices of the present invention are far greater than those developed in conventional spring connectors despite the fact that the shape and dimensions of the devices of the present invention must of necessity be similar to those of conventional spring connectors. In particular it is important that the amount of motion in the two types of connector should be approximately the same. Conventional springs are made as thick as possible consistent with giving the required degree of movement. Because stiffness increases with the cube of thickness, the movement required, combined with an elastic limit of 1% or less in conventional metals, severely limits the contact forces obtainable. In the preferred devices of the present invention, however, a conventional spring is used merely to generate a relatively low bias force which, on warming, is overcome by the other member which exhibits temperature-variable force/deflection characteristics. The force in the latter member is generally from 3 to 5 times larger than the bias force, resulting in an overall contact force of from 2 to 4 times greater than that which would be exhibited by a corresponding conventional spring connector.

Accordingly, it will be seen that the present invention provides a temperature-controllable device which will adopt a first stable configuration at one temperature and a second stable configuration at another temperature and which is re-usable even though it is capable of maintaining a secure contact at relatively high temperature. Preferably the two spring members are operably attached in an opposed manner so that they tend to work against one another, flexure of the second spring member being capable of inducing a flexure of the first spring member and vice versa and when the temperature of the article is raised or lowered through the transition temperature the change in force/deflection characteristics of at least one of the spring members results in an overall movement. When this member is made from a memory metal, especially an alloy of titanium and nickel, a connector capable of operation at high temperature results. It will be appreciated, however, that by appropriate choice of the relevant materials and by appropriate design modification the devices of the present invention will find use in many different environments.

The present invention will now be described in more detail, by way of example only, with reference to the accompanying drawings, in which

Figure 1 is a side elevation, partially in section, of one device according to the present invention;

Figure 1A is a graph showing a typical, desirable force vs. deflection relationship for the device of Fig. 1;

Figure 2 is a side elevation, partially in section, of a second device according to the present invention;

Figure 3 is a side elevation, partially in section, of a third device according to the present invention;

Figure 4 is a side elevation of a first spring member useful in a device of the present invention;

Figure 5 is a side elevation of a second spring member useful in a device of the present invention; and

Figure 6 is a side elevation of a third spring member useful in a device of the present invention.

Referring now to the drawings, the device shown in Figure 1 utilises a curved end cantilever spring 20 which is operably attached to a longitudinally loaded leaf spring 21. Spring 20 is inserted through an opening in base 22. Spring 21 is held in spring 20 by stop 25 and indentation 26. Stop 25 also positions spring 20 in base 22.

Spring 21 is fabricated from a material which has a relatively low modulus at low temperatures but a high modulus at high, e.g. ambient, temperature, and spring 20 is fabricated from a material which has a relatively high modulus at low temperatures. At low temperatures the device will attempt to assume a position such as that indicated by the phantom lines. As the temperature is increased, the longitudinal force exerted by member 21 also increases, and it will extend

into the position shown by the solid lines. If a circuit board 23 is placed between the device and base 22, a strong contact will be made between the printed circuit board and contact point 24 of spring 20 when spring 21 is at a temperature at which it has a relatively high strength.

The device shown in Figure 1 represents a particularly effective temperature-actuatable device for a reason which may not be readily apparent. This reason relates to the force deflection characteristics of spring 21. Although spring 21 is generally in the shape of a leaf spring, it is not loaded near its midpoint, but instead is only longitudinally loaded. By so loading spring 21, it will exert a relatively large force in a longitudinal direction when it is nearly straight. That is, it takes a relatively large force to deform spring 21 from its relaxed position, but once it has been partially deformed it will actually take less force to cause further deformation. Thus, unlike most springs, the force-to-deflection ratio is not constant but instead varies depending upon the amount of deflection. Stated differently, if a plot is made of force versus deflection for most springs, a straight line will result whereas with a longitudinally loaded leaf spring a curved line will result.

By choosing the proper combination of force/deflection characteristics of springs 20 and 21, it is possible to create a device which will tend to snap open and closed within a relatively small temperature change. This snap-action is obtained by choosing one spring member which has a force/deflection curve with a maximum therein, that is, the force/deflection curve should reach a maximum followed by at least some portion of decreasing slope.

A typical force/deflection curve for this first spring member is shown in Figure 1A. A device with a snap-action would result if the other spring was so arranged in relation to the first spring member that the deflection of the first spring member was on the left-hand side of the maximum when the device was in a first stable position and on the right hand side of the maximum when the device was in its second stable position.

Several types of spring exhibit a force/deflection curve with some negative slope and although a longitudinally loaded leaf spring affords a particularly simple method for achieving this snap-action, other non-linear springs may also be used. For instance, a Belleville spring may be shaped to have a highly non-linear force/deflection curve and if the ratio of the height to the thickness of the Belleville spring is properly chosen (one example being a Belleville spring having an outside diameter of 5 inches, an inside diameter of 2½ inches, a thickness of 0.040 inches and a height to thickness ratio greater than about 2.0), the force/deflection curve will have a maximum which may be utilized to produce a "snap" effect (see, for instance, Machine Design by J. E. Shigley-McGraw-Hill, 1956 which shows on page 237, Figs. 7 to 15, force/deflection curves for a series of different Belleville springs).

Referring now to Fig. 2, the device shown comprises a fork spring 30 having a tine 31 with a contact point 32. A longitudinally loaded spring 33 is held in grooves 34 and 35 of spring 30. Spring 30 is held in an opening 36 in base 37.

In order to bring about movement of the device, the temperature of the device of Figure 2 first lowered so that spring 33 requires a relatively low force to cause a deflection. For instance, if spring 33 is fabricated from an alloy having major proportions of titanium and nickel, the temperature should be decreased in order to convert the titanium-nickel alloy to its martensitic phase configuration. This decreases the force it exerts and thus weakens it with respect to spring 30 which can then deform spring 33 to a position shown by the phantom lines. Cooling may be carried out by means such as by spraying with a low boiling liquid which has been pressurized, suitable liquid coolants including tetrafluoromethane, chlorotrifluoromethane and trifluoromethane. Alternatively, cooling may be carried out by contact with ice or liquid nitrogen.

Printed circuit board 38 is then inserted against a portion of base 37 and the temperature of the device is then raised in order to increase the force exerted by spring 33 which then brings spring 30 and contact point 32 to the position shown by the solid lines. In this position, it is capable of exerting a relatively large force against board 38, since spring 33 adopts a nearly straight configuration.

In contrast to the devices shown in Figs. 1 and 2, the device of Figure 3 closes against an object at low temperatures. Cantilever springs 40 and 41 are mounted through base 42, and a spring member 43 is held in notches 44 and 45 of springs 40 and 41. Springs 40 and 41 are fabricated from a material which exhibits a relatively large change in modulus with temperature whereas spring member 43 is fabricated from a conventional material such as spring steel. When the temperature of the device of Figure 3 is high the spring member 43 will force springs 40 and 41 apart into a position indicated by the phantom lines of Figure 3. When the temperature is lowered the strength of springs 40 and 41 is relatively high with respect to that of spring member 43, the device will close to the position shown by the solid lines. Thus, if an object

46 is placed between the contact points 47 and 48 of springs 40 and 41, it will be held as shown.

Various spring configurations are shown in Figures 4 through 6. These springs can be used in devices of the type shown in Figures 1 through 3. Although the devices of the type shown in Figures 1 and 2 were described as if the longitudinal leaf spring-like member was fabricated from a material whose modulus changed substantially with temperature, the device could also be made where the member which corresponds to member 21 of Figure 1 is fabricated from a material having a relatively temperature-constant modulus. The other spring should then be fabricated from a material whose modulus changes substantially with temperature. For instance, if the device of Figure 1 were fabricated so that spring 20 was made from a titanium/nickel alloy, the device would tend to seek the position shown by the solid lines at low temperatures and the shape shown by the phantom lines at high temperatures.

ALTERNATIVE

It is significant to note that the movements brought about in the devices of the present invention do not require that there be a dimensional or length change in one of the spring members. It is a change in force/deflection characteristics which brings about a movement rather than a dimensional change. In this way, the devices of the present invention differ in kind from bimetallic members which depend upon differential expansion or contraction with temperature. Changes in properties such as the secant modulus bring about a change in the force/deflection characteristics of a spring. For example, the alloys having about equal atomic proportions of titanium and nickel typically have a secant modulus of about 850,000 PSI at a strain of 5% when in the martensitic phase and a secant modulus of about 12,000,000 PSI at a strain of ½% when in the austenitic phase.

The devices of the present invention have the potential advantage of being fabricated wholly from metals, and thus can be made to withstand great temperature extremes. The allow TiNi remains strong at high temperatures; for instance, the Young's modulus of TiNi at 600°C is about 14,000,000 PSI and the strength of many spring steels remains high at 600°C.

WHAT WE CLAIM IS:—

1. A temperature-actuatable snap-action device which assumes one configuration above a transition temperature or temperature range and another configuration below said transition temperature or temperature range, which device comprises two interacting spring members at least one of which exhibits a substantial change in force/deflection characteristics on passing through the transition temperature or temperature range and at least one of which has a non-linear force/deflection curve having a maximum therein through which it passes as the device snaps from one configuration to the other.

2. A device as claimed in claim 1, wherein one spring member exhibits a negligible variation in force/deflection characteristics with temperature.

3. A device as claimed in any one of claims 1 or 2, wherein one spring member, whose force/deflection curve passes through a maximum, also exhibits a substantial change in force/deflection characteristics on passing through the transition temperature or temperature range.

4. A device as claimed in claim 3, wherein the deflection of said spring member below the transition temperature or temperature range lies on one side of the maximum in its force/deflection curve at that temperature and the deflection of said spring member above the transition temperature or temperature range lies on the other side of the maximum in its force/deflection curve at that higher temperature.

5. A device as claimed in any one of claims 1 or 2, wherein one spring member, whose force/deflection curve passes through a maximum, does not exhibit a change in force/deflection characteristics on passing through the transition temperature or temperature range.

6. A device as claimed in claim 5, wherein the deflection of said spring member below the transition temperature or temperature range lies on one side of the maximum in its force/deflection curve and the deflection of said spring member above the transition temperature or temperature range lies on the other side of said maximum.

7. A device as claimed in any one of claims 1 to 6, wherein the or each spring member which exhibits a substantial change in force/deflection characteristics on passing through the transition temperature or temperature range is made from a metal.

8. A device as claimed in claim 7, wherein the metal has a higher modulus of elasticity above the transition temperature or temperature range than below it.

9. A device as claimed in claim 7 or claim 8, wherein the metal is an alloy of nickel and titanium.

10. A device as claimed in claim 9, wherein the alloy comprises about equal proportions of titanium and nickel.

11. A device as claimed in any one of claims 1 to 6, wherein the or each spring member which exhibits a substantial change in force/deflection characteristics on passing through a transition temperature

or temperature range is a polymer of a non-metallic elastomer.

12. A device as claimed in any one of claims 1 to 11, wherein the transition temperature or temperature range lies below ambient temperature.

13. A device as claimed in any one of claims 1 to 12, wherein one of said members is a longitudinally loaded leaf spring.

14. A device as claimed in any one of claims 1 tc 12, wherein one of said members is a Belleville spring.

15. A device as claimed in claim 13 or claim 14, wherein the other spring member has two tines and the leaf spring or the Belleville spring is located between the tines.

16. A device as claimed in claim 15, wherein the other spring member is a curved end cantilever spring and the leaf spring or the Belleville spring is located across the curved end thereof.

17. A device as claimed in any one of claims 1 to 16, which is, or is part of, a connector.

18. A device as claimed in claim 1, substantially as described herein with reference to, and as illustrated in, Figure 1, Figure 2 or Figure 3 of the accompanying drawings.

19. A method of making a connection which comprises bringing an object or objects into contact with a device as claimed in claim 17, and then effecting the temperature change necessary to actuate the device.

20. A method as claimed in claim 19, wherein the temperature change is a rise in temperature.

21. A method as claimed in claim 19 or claim 20, wherein a connection is made to a printed circuit board.

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snap open & closed with temperature changes

1439848 COMPLETE SPECIFICATION

1 SHEET

This drawing is a reproduction of the Original on a reduced scale

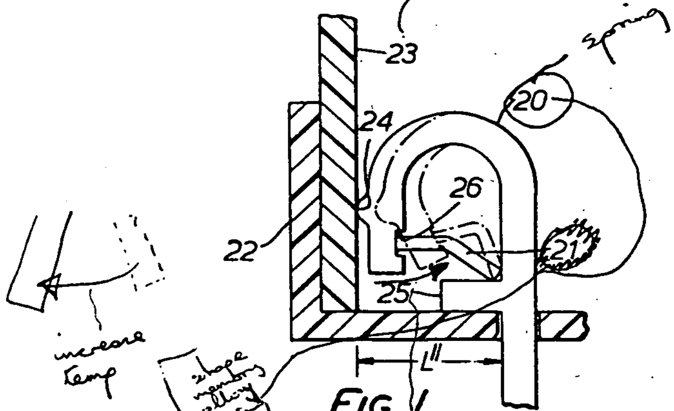

FIG. 1.

Alternative as per p 5

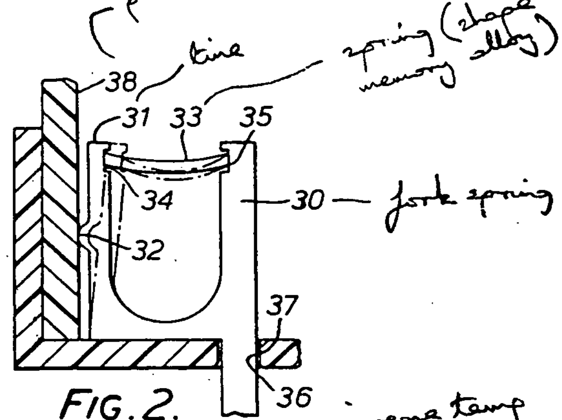

FIG. 2.

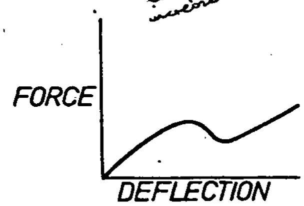

FIG. 1A.

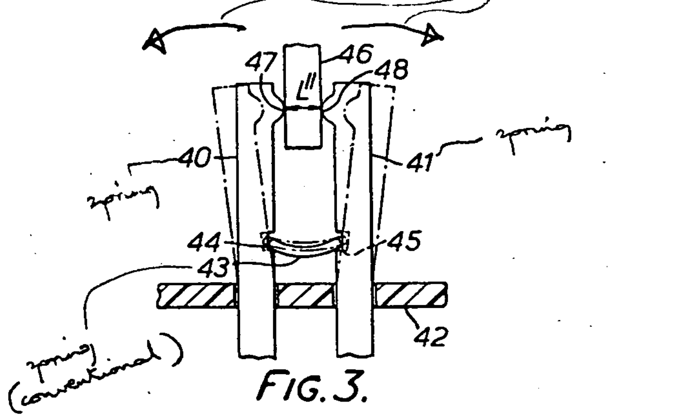

FIG. 3.

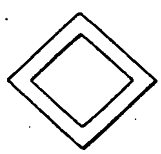

FIG. 4.

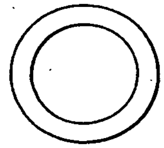

FIG. 5.

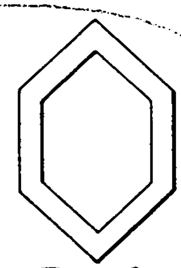

FIG. 6.

spring configurations for Figs. 1 to 3